Bottomium production & $B_s$ Mixing at the DØ experiment

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DØ collaboration
B-Physics at DØ

• Large b-quark production cross section: \( \sim 30 \, \mu b \)
• all kind of b-hadrons produced (\( B_d, B_s, B_c, \Lambda_b \) ...)

• Huge spectrum of analyses:
  • Production: differential cross sections, helicity....
  • B-Properties: Life time, mass, decays ...
  • \( B_s/B_d \) mixing
  • New Particles, new physics

• Huge background \( \rightarrow \) need effective trigger

• Complicated event structure (many tracks)

Here:
• bottomium production (\( \Upsilon(1S) \))
• \( X(3872) \) (possible charmonium state)
• \( B_s \) mixing
Tevatron and DØ Detector

Recorded data: \( \sim 1.2 \text{ fb}^{-1} \)
Efficiency: 85-90 \%

+ very good muon system
- Compact tracking system
Muon system:
- 1.8 T toroid field
- Large angular acceptance (up to $\eta = |2|$)
- Trigger highly efficient (close to 100% for $p_t(\mu) > 5$GeV)
- Unbiased (impact parameter cuts only for highest luminosity)

Tracking:
- Huge tracking density capability
- Angular coverage up to $|\eta| = 3$
Bottomonium production

- insight into the nature of the strong force
- factorized into two steps:
  - production of a heavy quark-antiquark pair
  - two quarks forming a particle of a color-singlet quarkonium state
- Measurement: test of different models
- Models differ in cross sections and polarisation
- Recent phenom. paper (Phys. Rev. D 71 034007 (2005)) describes data at Tevatron RunI (CDF result with coverage of $|y|<0.4$)
- New DØ analysis: $|y|<1.8$, and differential cross section in $p_t$ and $y$
• $L=160\text{ pb}^{-1}$
• Di-muon trigger
• Two opp. Charged muons with $p_t>3\text{ GeV}$, $|y_{\mu}|<2.2$
• Total sample: $\sim 50000$ events
• Acceptance: 15...28%
• Trigger efficiency: 70...82%
• Corrections for data/mc differences in tracking, triggering, quality (e.g. Cosmics): 0.7...0.95
• Clear $\Upsilon(1S)$ signal
• $\Upsilon(2S), \Upsilon(3S)$ not resolvable

$p_t$ bin: $4\text{ GeV}<p_t(\Upsilon)<6\text{ GeV}$
Cross section

- Total $\Upsilon(1S)$ cross section:
  - $695\pm14\text{(stat)}\pm68\text{(sys)}\pm45\text{(lumi)}\text{pb}$
  - $|y|<1.8$

- Differential cross section:
  - 9 bins $p_t$
  - 3 bins $y$
  - $y<0.6$: agreement with CDF $|y|<0.4$

- Lower plot: ratio between result for $|y|<0.6$ and $1.2<|y|<1.8$: no deviation to theory
X(3872) -> J/ψπ⁺π⁻

• Is X(3872) a charmionum mode?
• Selection: X(3872) → J/ψ(μ⁺μ⁻)π⁺π⁻
• Luminosity: 230 pb⁻¹
• 522 ± 100 events
• \(\Delta m := m(J/\psi \pi^+\pi^-) - m(J/\psi) = 774.0 \pm 3.1 \text{(stat)} \pm 3.0 \text{(sys)} \text{MeV}\)
$X(3872) \rightarrow J/\Psi \pi^+ \pi^-$

- Comparison of 5 kinematic variables with $\Psi(2S) \rightarrow$ very similar distributions
- compatible to J=1$^-$, 1$^{++}$ and 2$^-$

Fraction of:

a) $p_t > 15$ GeV
b) $|y| < 1$
c) $\cos(\theta_{\pi})$
d) $d_1 < 0.01$cm
e) isolation = 1
f) $\cos(\theta_{\mu})$
**Goal:** $V_{td}$ measurement

**Measurement of $\Delta m_d$ and $\Delta m_s$:**

\[
\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s^0}}{m_{B_d^0}} \cdot \frac{B_{B_s^0}}{B_{B_d^0}} \cdot f_{B_s^0}^2 \cdot \left| V_{ts} \right|^2 \cdot \left| V_{td} \right|^2
\]
Measurement Principle

Reconstructed side

Opposite side

- Final state reconstruction:
  - b-flavor at decay
  - b momentum (missing: p_ν)

- Proper lifetime: \( c\tau = m_B \frac{L_{xy}}{P_T(B)} \)

- Initial state (opposite side):
  - lepton charge
  - sec. vtx/lepton jet charge
Data samples

- Very big untagged $B_s$ sample (~26.7k)

- After initial flavour tagging ~5.6k
  $\varepsilon = 21.0\%$; $\varepsilon D^2 = 2.48\%$

![Graphs showing DØ Run II data](image)
DØ B\(_s\) mixing limit: Asymmetry

Unbinned Fit of amplitude:
- "probability density functions"
  - Mass distribution
  - Resolution
  - Dilution

Asymmetry(t) = A \cdot D \cdot \cos(\Delta m \cdot t)

\[
\text{Asymmetry}(t) = \frac{N(t)_{\text{unmixed}} - N(t)_{\text{mixed}}}{N(t)_{\text{unmixed}} + N(t)_{\text{mixed}}}
\]
$\Delta m_s$ measurement

$\Delta \log(L)$ for different $\Delta m_s$ and fixed $A=1$:

Asymmetry(t) = $A \cdot D \cdot \cos(\Delta m \cdot t)$

$17 \text{ps}^{-1} < \Delta m_s < 21 \text{ps}^{-1}$
(90% CL assuming Gaussian error)

Unitarity triangle

\[
\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_s^0} \cdot f_{B_d}^2}{m_{B_d^0} \cdot f_{B_s}^2} \cdot \frac{|V_{td}|^2}{|V_{ts}|^2}
\]

without DØ

\[
\sin 2\beta \quad \Delta m_s & \quad \Delta m_d
\]

|\epsilon_K|, |V_{ub}/V_{cb}|, |\gamma|

\(\Delta m_s \quad \Delta m_d\)

sol. w/ \(\cos 2\beta < 0\)
(excl. at CL > 0.95)

with DØ result

(Theoretical error dominates uncertainty)

\[\text{excluded area has CL > 0.95}\]

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Summary

- **DØ**: large spectrum of B-physics analyses with up to 1fb$^{-1}$ data
- **Bottomium $\Upsilon(1S)$**:  
  - Cross section: $695\pm14$(stat)$\pm68$(sys)$\pm45$(lumi) $|y|<1.8$  
  - Differential cross section: no deviation from theory,
- **$X(3872)$ → compatible with charmionium state**
- **Bs mixing measurement**  
  - Amplitude method:  
    - Sensitivity $\Delta m_s > 14.1$ps$^{-1}$ mit 95% CL  
    - Limit $\Delta m_s > 14.8$ps$^{-1}$ mit 95% CL  
  - Log likelihood of $\Delta m_s$:  
    - $17$ps$^{-1}<\Delta m_s<21$ps$^{-1}$ (90% CL, assuming gaussian error)  
    - New CDF result: $17.33\pm0.42\pm0.07$ ps$^{-1}$
CDF result

- Result dominated by hadronic Channel
- Impact parameter trigger
- Good same side (Kaon) tagging

\[ \Delta m_s = 17.33^{+0.42}_{-0.21} \text{(stat.)} \pm 0.07 \text{(syst.)} \text{ps}^{-1} \]

Systematic dominated by the \(ct\) scale, any other effect very small